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An Engineering and Economic Analysis of the Prospects of Reallocating Radio Spectrum from the Broadcast Band through the Use of Voluntary Incentive Auctions

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I. EXECUTIVE SUMMARY

Voluntary incentive auctions for the spectrum currently occupied by television broadcasters should be an important part of meeting exploding demand for radio spectrum. Despite recent allocations of licensed spectrum and demand management techniques for wireless carriers, such as WiFi offloading and innovative pricing schemes, significant amounts of additional spectrum will be required to satisfy growing demand on wireless broadband networks. Based on the Principle of Spectrum Reallocation[1], additional frequencies should be reallocated to high-valued wireless broadband uses whenever such uses are more valuable than the existing uses of spectrum bands. Voluntary incentive auctions, where proceeds from auctioning the reallocated spectrum compensate existing licensees, ensure that spectrum will only be reallocated when it is more valuable in its new use. This paper focuses on reallocation of a portion of the television broadcast band via a voluntary incentive auction process.

We perform a detailed analysis of repacking television channels so as to minimize the required compensation needed to induce current broadcasters to return their UHF broadcasting licenses. The costs of repacking—based on new equipment needed for an existing broadcaster to continue broadcasting to the same service area on a different channel—are estimated to average $885,500 per full power station and $267,375 per low power station. Based on our calculations, this is a total of $775 million for all stations. Each repacked station would remain on its existing tower, thus minimizing or eliminating any concerns about replicating the coverage of the original broadcast signal.

Broadcasters who choose to take the opportunity to return their UHF licenses in exchange for compensation in an incentive auction have several alternatives to continue broadcasting—they could co-broadcast with another broadcaster, obtain a license to broadcast on VHF channels, modify their coverage area or negotiate to have their programming carried on non-broadcast video delivery systems. In fact, there are several broadcast platforms that have with substantial

[1] See the Principle of Spectrum Reallocation as discussed in "Oral Testimony of Coleman Bazelon," *The Brattle Group, Inc.* U.S. House of Representatives, Committee on Energy and Commerce Subcommittee on Communication and Technology (April 12, 2011). Found at: http://democrats.energycommerce.house.gov/sites/default/files/image_uploads/Testimony_04.12.11_Bazelon.pdf (last visited June 20, 2011).

viewership that do not rely on VHF/UHF transmissions. These include cable, satellite and internet video services such as Hulu. Our analysis forecasts the expected compensation that could be required to induce broadcasters to participate in an incentive auction. We estimate conservatively that the upper bound of total payments to broadcasters could be as high as $15.2 billion to clear 120 MHz.

Our forecast of auction revenues is based on previous comparable auction results, adjusted for changing market conditions. In particular, we adjust for the added supply of spectrum created from these incentive auctions as well as the change in spectrum value over time. We estimate that the auction of 120 MHz of spectrum currently occupied by TV broadcasters would raise $40.0 billion.

In sum, we expect that voluntary incentive auction of the broadcasting spectrum band would transfer 120 MHz of highly valuable spectrum to wireless broadband uses and raise $24.7 billion for the U.S. Treasury (after paying the reserve auction winners from the gross proceeds). This transfer would reallocate spectrum to uses with a far greater benefit to the U.S. economy than the current uses. At the same time, every broadcaster whose bid is accepted will receive compensation at least as high as the value the broadcaster has placed on its current license. Repacked stations will receive new equipment to replace old at no expense to the broadcaster.

The estimated value of this spectrum to wireless firms—$40.0 billion—is only a fraction of the social value created by reallocating spectrum currently used for television broadcasting to wireless broadband uses. The long run benefits from more wireless broadband at lower cost is far more important to American society than the government revenues. The benefit to consumers is estimated to be 10 to 20 times the value of the spectrum to producers.

II. INTRODUCTION AND OVERVIEW

The recent explosive growth in demand for capacity on wireless networks is expected to increase dramatically over the coming years. Several well-known studies have predicted that wireless data demand will increase at least 26 fold from 2010 to 2015.[2] The FCC itself projects that by 2014, such demand will be 35 times the level in 2009.[3] As in the past, some portion of the increased demand will be met by new technologies. For example, deploying LTE technologies will likely double capacity over current 3G technologies.[4] Other capital investments in networks—largely the increasingly expensive approach of dividing cells—will further increase the capacity of existing networks. Some of the increased demand will also be met by various demand management techniques, such as WiFi offloading, off-peak transmission and on-device storage, and pricing schemes designed to mitigate peak demand. Even if successfully implemented, these demand and efficiency management techniques are not expected to be able to accommodate the growing demand for mobile broadband services. Despite all of these other approaches, additional radio spectrum allocated to mobile broadband will be needed very soon to meet consumer demand at affordable prices.

Currently, there is approximately 600 MHz to 700 MHz of licensed radio spectrum on a 700 MHz equivalent value basis available for mobile broadband services in the U.S. See Table 4 below. This existing spectrum represents a substantial increase over the initial 40 MHz on which

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2 See Cisco, "Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2010–2015," White Paper, February 2011, downloaded on March 18, 2011 from: http://www.cisco.com/en/US/solutions/collateral/ns341/ns525/ns537/ns705/ns827/white_paper_c11-520862.html. See also, Rysavy Research, "Spectrum Shortfall Consequences," White Paper sponsored by NTIA, April 21, 2010, downloaded on March 18, 2011 from: http://www.rysavy.com/Articles/2010_04_Rysavy_Spectrum_Shortfall_Filing.pdf (herein "Rysavy 2010").

3 See "Mobile Broadband: The Benefits of Additional Spectrum," FCC Staff Technical Working Paper, October 2010, Federal Communications Commission, Washington DC, p. 9. (herein FCC "Benefits of Broadband," 2010)

4 Determining the increased capacity of a network is dependent on a number of factors, including the type of hardware and software used with the system and the size of the spectrum band. Rysavy 2010 writes that "deploying a 10 MHz LTE radio channel costs almost the same as deploying a 5 MHz HSPA channel, but the LTE channel has about four times the capacity" (see page 7). Consensus among the experts suggests that the spectral efficiency of LTE is generally twice that of 3G technology (specifically, UMTS/HSPA technology). The spectral efficiency of 5 MHz versus 10 MHz of LTE drops by around 3%, from around 98% to 95% of 20 MHz efficiency. (See Figures 8 and 21 in Rysavy Research, "HSPA to LTE advanced: 3GPP Broadband Evolution to IMT-Advanced (4G)," White Paper sponsored by 3G Americas, September 2009, downloaded on March 18, 2011 from: http://www.3gamericas.org/documents/3G_Americas_RysavyResearch_HSPA-LTE_Advanced_Sept2009.pdf).

cellular began in the 1980s.[5] But, between the 1980s and today, wireless has changed from an expensive service used by only a few in developed nations to the most widely used voice and data communications technology in the world today. The PCS, AWS, 2.5 GHz, and 700 MHz allocations all represent very important expansions in the base of licensed spectrum available for mobile broadband services.

Recognizing both growing demand for wireless services and a sizable base of spectrum allocated to support those services, there are at least two reasonable questions to ask: "How do we know if more spectrum should be allocated to mobile broadband services?"; and "How will we know when sufficient spectrum has been allocated to broadband services?" These questions are best answered using a straightforward principle of spectrum reallocation: if a higher valued use exists, spectrum should be reallocated from the lower valued use to the higher valued use. By this Principle of Spectrum Reallocation more licensed spectrum should be allocated to support mobile broadband services so long as any given band of spectrum is more valuable supporting mobile broadband services than in its current or other alternative uses.[6]

Because most spectrum available for mobile broadband trades reasonably freely and is allocated for flexible use, we can be reasonably confident that it is being put to its highest valued use when used to support mobile broadband services. (For example, a PCS licensee could have the option of using its spectrum for fixed microwave datalinks or for services much like broadcasting, but instead chooses to use it for mobile broadband networks.) Because mobile broadband service is typically the highest valued commercial use, the market price for licensed spectrum for mobile broadband networks is a good measure of its value.

All spectrum other than that listed in Table 4 contains use and/or ownership restrictions that mean market-based valuations either do not exist (for example, for spectrum allocated to the

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5 The FCC's initial 40 MHz cellular spectrum allocation was increased to 50 MHz in 1986. For more history of the early cellular band see FCC's Cellular Band Plan: http://wireless.fcc.gov/services/index.htm?job=service_bandplan&id=cellular.

6 Technically, this conclusion assumes that wireless broadband is the highest valued use that reallocated spectrum can be put to. For more discussion on the relative value and reallocation of licensed radio spectrum, see Coleman Bazelon, "The Need for Additional Spectrum for Wireless Broadband: The Economic Benefits and Costs of Reallocations," White Paper sponsored by the Consumer Electronics Association (CEA), October 23, 2009 (herein Bazelon, "The Need for Additional Spectrum," 2009).

government) or do not reflect uses such as mobile broadband (for example, spectrum restricted to fixed microwave datalinks or television broadcasting.) The value of spectrum that is not traded can be estimated through standard financial and economic techniques. Such estimates of value should in principal be based on all sources of value for that spectrum allocation, including so-called non-market benefits such as the social benefits from public safety, education, and community outreach.[7] The proposition that spectrum should be allocated to its highest valued use suggests that any spectrum (properly) valued less than mobile broadband spectrum should be reallocated to support mobile broadband services.

The Principle of Spectrum Reallocation quickly leads to two follow-on questions. First, how do we know which use is most valuable? Second, how will the existing users of a band targeted for reallocation be adequately compensated for losing access to (some or all of) the spectrum they currently use if it is reallocated? These questions can be answered simultaneously through the use of voluntary incentive auctions. In the context of spectrum allocations, a voluntary incentive auction is a two-sided auction in which, on the one hand, incumbents who opt to participate will bid the amount they need to be compensated to give up their current spectrum licenses and, on the other hand, prospective users of the reallocated spectrum bid for the new spectrum licenses. In a voluntary incentive auction, receipts from the auction generate a pool of revenues. A portion of these revenues can be used to compensate the incumbent spectrum users who bid to return a current license. **Put simply, voluntary incentive auctions assure that spectrum will be reallocated only when its proposed new use is more highly valued than its existing use.[8]**

Recently, several different proposals to use voluntary incentive auctions to reallocate a portion of the spectrum currently occupied by television broadcasters have been put forward by the FCC, the White House, draft legislation in the U.S. House and Senate, and at least two industry trade associations.[9] The core notion is that participating broadcasters that currently use UHF

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7 It is beyond the scope of this paper to evaluate the relative value of additional spectrum in non-market uses such as national defense or public safety.

8 This analysis focuses on the benefits as measured by the licensees. It does not consider the benefits for broadcast viewers or wireless users. Given the existence of alternatives to over-the-air broadcasting and the widespread demand for wireless services, we believe that these consumer benefits also favor reallocation to wireless—perhaps even more reallocation than the incentive auction would yield.

9 See "Spectrum Analysis: Options for Broadcast Spectrum," OBI Technical Paper No. 3, June 2010, Federal Communications Commission, Washington DC (herein "OBI Technical Paper No. 3 2010"). See

frequencies will bid amounts they would need to be compensated to vacate their existing channels. These proposals offer various solutions for what broadcasters could do in the alternative, including switching to a cable-only distribution, sharing a broadcast signal with another broadcaster, reducing their coverage areas and broadcasting on a VHF frequency. Any auction that allows for more alternatives to relinquishing a current UHF license—such as co-broadcasting, moving to VHF or reducing service area—will likely be less costly than the estimates presented herein. Likewise, as discussed below, a series of separate auctions would reduce clearing costs and increase value.

In each proposal, bids for the reallocated stations are taken, and spectrum is reallocated only if these bids exceed some required threshold. The threshold of required bids in the forward auction may simply be enough to fairly compensate broadcasters for relinquishing their license or moving to a new channel, or it may include some minimum additional revenue for the Treasury. There are many variations on how a voluntary incentive auction for the spectrum bands currently occupied by TV broadcasters could be structured. Below we describe general features of such an auction, but recognize that a significant number of details remain to be worked out before such an incentive auction can be implemented.

These proposals—including the one presented here—differ on how they determine the number of stations needed to voluntarily return their UHF licenses, the level of compensation these stations might require, as well as the channel assignments for the remaining stations. Another proposal considers each market independently, concentrating only on the top 30 markets, and relies exclusively on basic assumptions regarding the channel spacing within that market. Similar to the analysis below, the FCC study utilizes a nationwide approach to repacking in which they consider all channel and co-channel interference constraints both within each market and between markets. The benefit of our approach is that it shows that a feasible repacking, taking account of all existing engineering constraints, exists. Our algorithm differs from the FCC's in that they attempt to find a global optimal allocation – we only attempt to approximate one. In

also "Broadcast Spectrum Incentive Auctions," White Paper Sponsored by CTIA/CEA, February 15, 2011 (herein "CTIA/CEA 2011"). See also White House, "Winning Through the Future: 2012 Budget," Fact Sheet, downloaded March 18, 2011 from http://www.whitehouse.gov/omb/factsheet/winning-the-future-through-innovation. See also draft bill "S. 911—Public Safety Spectrum & Wireless Innovation Act" currently under consideration in the U.S. Senate.

other words, the FCC's algorithm is designed to identify the solution that best matches their objective criteria.[10]

The other analysis further assumes that stations returning their UHF license will accept compensation equal to their enterprise value. We present a more conservative approach, which assumes that all stations within a market must be compensated at the same bid-clearing price, equal to the lowest bid that is not accepted.[11] As discussed below, compensating each bidder at this amount (the marginal bid value) is one way to create the incentives that will cause bidders in an auction to bid truthfully, reducing the risk of problems such as hold-out and collusion. Other approaches may be less costly. Further, offering additional alternatives to turning in a license would likely further reduce required compensation to broadcasters. Consequently, our projected costs represent upper-bounds of potential payments for any well-designed auction.

Independent of the alternatives, we first performed an analysis to identify the set of stations that we expect would offer the lowest bids in the reverse auction and take the opportunity to return their UHF broadcasting license. Based on these stations, we calculated the expected compensation that these broadcasters would receive at auction, and repacked the remaining UHF broadcast stations (with compensation to cover costs) and clear bands of spectrum for higher valued uses.

In Section III we discuss the key features of a voluntary incentive auction, particularly how it can be applied in the context of spectrum licenses currently held by broadcasters. In Section IV, we propose a methodology for repacking the existing broadcasters in order to free up spectrum for wireless broadband use. We conclude this section by presenting the results from our repacking analysis. Then, in Section V, we estimate the auction revenues for the cleared spectrum. Section VI analyzes the robustness of our results. The final section provides a conclusion and summary of our analysis.

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10 For instance, some of the criteria suggested in the FCC's OBI Technical Paper No. 3 2010 (see p. 48) include minimizing the number of stations changing channels, and minimizing the number of stations that must return a license.

11 This amount, the marginal bid, is the lowest amount at which there will not be more stations willing to be bought out than are needed. There is a substantial economic literature establishing that this amount would, at least on average, be elicited in an auction conducted under familiar auction formats.

III. THE VOLUNTARY INCENTIVE AUCTION

A voluntary incentive auction is a combination of a *reverse,* or procurement, auction and a *forward,* or regular, auction. Our intent here is to describe the general features of these auctions and discuss a few issues pertinent to designing a voluntary incentive auction. The details of both the reverse and forward auction would be worked out by the FCC in the regular course of its proceedings to establish auction rules, as the FCC has done with auctions in the past.

A. THE REVERSE OR PROCUREMENT AUCTION

In the reverse auction, broadcast station licensees bid an amount for which they would be willing to return their current UHF broadcast licenses. In our analysis we make no assumption about what stations would do in the absence of broadcasting under their existing licenses.[12] There are alternative auction structures not examined here—for example, where licensees could bid separate amounts to give up their license, share with another broadcaster, or move to a VHF channel.[13] Such an auction would reduce the expected compensation required for existing licensees to relinquish their current broadcast licenses, because they would be less costly to a licensee than giving up a license entirely. Similarly, reallocating spectrum from the broadcast bands in a series of auctions would be less costly, because the market clearing price in each separate reallocation would be lower or apply to fewer broadcasters.

Consequently, the approach we take is highly conservative and likely overestimates payments to broadcasters. Our estimates should be interpreted as an upper bound on the costs to clear incumbent broadcasters. We believe that actual costs would be lower than our estimates, as we expect that many broadcasters would be willing to take advantage of these alternatives and that their bids would reflect these gains.

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12 As explained in more detail below, one exception to this is that we identify a number of educational licensees that would be likely to participate because they broadcast in close proximity to each other and would be candidates for sharing a broadcast signal.

13 See "Incentive Auctions: New Options for Broadcasters," FCC State Broadcasters Association Webinar Series, March 2011, pp. 6-7. Available at: http://iowabroadcasters.com/resource/tvweb311.pdf (last visited April 22, 2011). See, also, "The FCC's Incentive Auction Proposal: New Options for Broadcasters," Remarks by Bill Lake, Chief, Media Bureau, FCC, To the National Alliance of State Broadcaster Association, February 28, 2011, pp. 6-7. Available at: http://www.fcc.gov/Daily_Releases/Daily_Business/2011/db0301/DOC-304900A1.pdf (last visited April 22, 2011).

A key consideration in designing an auction is to create incentives for bidders to bid in a manner that reflects the bidder's economic reality, and minimize incentives for bidders to not truthfully bid their value or hold out for more than they are actually willing to accept. We do not want to address the details of auction design here, but would leave it to the FCC to design an auction with incentives for bidders to bid truthfully. For purposes of estimating payments to broadcasters, we use the rule that each broadcaster in a market whose bid is accepted will be paid the lowest bid of the broadcasters in the market whose bids were not accepted. Paying this amount, as opposed to the amount actually bid by a broadcaster, is one approach to inducing truthful bidding—there may be other approaches that reduce the total payments to broadcasters. This issue is discussed further in Section VI, below.

Regardless of auction design, an important consideration for any auction to be successful is that there must be sufficiently more bidders than bids needed so that no bidder has hold-out power. In the current context, this means that the number of licensees needed to return their licenses to achieve a target amount of spectrum for reallocation must be strictly fewer than the number of licensees in the market that would bid in the auction. Clearly, commercial licensees would consider the option of bidding in the auction—it would be permissible, but potentially irresponsible to the commercial interests that own the license, for a commercial licensee to opt not to participate by offering a bid, even if it is relatively high and unlikely to be accepted. The likelihood of noncommercial licensees bidding, however, is more uncertain. Prior to the auction, the exact number of excess bidders needed to avoid the hold-out problem cannot be known. Clearly there must be at least one, although more than one may be desirable.

One important factor mitigating holdout power of broadcast licensees is that no one broadcaster's license is ever strictly required to be relinquished. Given the trade-offs between markets in the placement of television channels, even the number of licenses in a market that would need to be relinquished is not definitive. For example, if a broadcaster in Washington, DC were to hold-out for higher payments, a broadcaster in a neighboring market such as Baltimore, MD could be substituted for the licensee attempting to hold out.[14] Consequently,

[14] As a result of interference separations (discussed below in Section IV.A), a channel that is used by a broadcaster in Baltimore, MD cannot also be used in Washington, D.C. Consequently, removing a

because all markets are interconnected through interference separations, the assessment of hold-out power in a market cannot be examined in isolation.

Another issue specific to incentive auctions that the FCC would have to carefully consider is the application of anti-collusion rules. As in any auction, it is undesirable to allow bidders to collude in a voluntary incentive auction. However, given that one option for bidders is to partner with another licensee to share a broadcast signal, in this particular auction it might be undesirable to prohibit all communication among bidders prior to the auction. This is a thorny issue that will require balancing the interests of preventing collusion and facilitating licensees to develop alternative means to broadcast their programming more efficiently or at lower cost.

B. The Forward Auction

The forward auction would be a standard FCC spectrum license auction. Many design issues are relevant to crafting a successful auction, including the optimal license size, potential license restrictions, build-out rules, and combinatorial bidding procedures.[15] For this analysis, we assume the FCC designs an auction that performs as well as its more successful auctions in the past.[16]

One feature of FCC auctions worth noting for a voluntary incentive auction is the reserve price for purchasing the spectrum. In an auction, the reserve price stipulates that the total amount bid for an entire auction, for a band within an auction, or for an individual license must exceed some threshold amount. For example, in the 2006 AWS auction, total provisional bids had to exceed \$1.03 billion for the auction to become official.[17] This number was set to cover the expected costs of clearing incumbent federal government users out of the bands that were auctioned. In the case of a voluntary incentive auction, the reserve price could be set to cover at least the

broadcaster in Baltimore, MD frees up a channel that may be used in Washington D.C. or some other neighboring market to Baltimore, MD.

15 For one analysis of how auction design issues can affect auction efficiency, see Coleman Bazelon, "Too Many Goals: Problems with the 700 MHz Auction," *Information, Economics and Policy*, April 2009 (herein Bazelon, "Too Many Goals," 2009).

16 We describe the reverse auction and the forward auction separately. However, the two auctions could be combined—with each informing the other. Describing the auctions separately makes the fundamental points easier to see.

17 See FCC Auction 66 website, http://wireless.fcc.gov/auctions/default.htm?job=auction_summary&id=66 (last visited March 18, 2011).

payments to broadcasters needed to clear the spectrum being auctioned as well as any revenues for the Treasury (or other purposes), as Congress deems appropriate.

C. THE QUANTITY OF SPECTRUM AUCTIONED

Unlike typical FCC spectrum license auctions, in an incentive auction, the amount of spectrum sold could be determined during the auction. In determining the amount of spectrum to auction, at a minimum to satisfy the Principal of Spectrum Reallocation the costs of clearing the spectrum should be covered by the auction receipts. As the quantity of spectrum cleared and auctioned increases, both the costs of clearing the spectrum and the expected revenues from the auction increase, but at differing rates. The more spectrum cleared, the greater the number of television stations that will need to be paid to relinquish UHF broadcasting licenses. Adding an additional station to the set that must be compensated in a given market increases total costs for two compounding reasons. Not only does it add an additional station that must be paid, but under the approach we take to estimating payments to broadcasters it also increases the per station payment made to *all* stations returning their current UHF broadcast licenses. In order to accept an additional broadcast station bid, the auction clearing price for all accepted bids increases to the next lowest bid not accepted. Consequently, the cost of clearing spectrum not only increases the more spectrum is cleared, but also increases at an increasing rate.

Meanwhile, the revenues from auctioning the cleared spectrum continue to increase with more spectrum cleared, but at a decreasing rate. The more spectrum auctioned, the higher the revenue that would be expected from the auction. However, as more spectrum is put on the market, the incremental revenue from each additional quantity auctioned decreases due to the lower price received for all spectrum sold. Consequently, revenues would increase but at a decreasing rate. The implication of these two effects is that at some point the total cost of clearing spectrum may exceed the total value of spectrum sold. At what point this might happen is an empirical question and can be determined within the auction. As reported below, our analysis indicates that the revenue from auctioning 120 MHz significantly exceeds our estimate of the upper bound of expected payments to broadcasters to free up that amount of spectrum.[18] Figure 2 illustrates this point at the end of this paper.

IV. REPACKING ANALYSIS

We use *repacking* to refer to the process of calculating the assignment of frequencies to television stations in specific cities without any diminution of their service area. The repacking approach we employed is based on both engineering and economic considerations. We rejected approaches based solely on engineering criteria. For example, if the objective is to minimize the total number of stations that relinquish their broadcast licenses, then consideration is not given to the value of the stations that go off the air. Instead, we propose repacking stations with the goal of finding a low-cost solution to freeing up a target amount of spectrum. Our approach to deciding how to repack the TV band explicitly considers the expected payments made to stations that would return their UHF licenses.

A. DATA AND METHODOLOGY

In order to determine a feasible repacking method for existing U.S. UHF television stations that does not reduce the coverage area of any station, we identified the U.S. station locations and broadcast frequencies, as well as any potential interference concerns with U.S. land mobile stations and border stations in Canada and Mexico. We obtained information, including tower location, channel assignment, and call number, on all U.S. UHF TV stations from the FCC's CDBS public database files.[19] This information identified a total of 1,712 full power broadcasters and 495 Class A broadcasters in the UHF and VHF bands of the continental U.S. Focusing on the UHF band, we identified 1,258 full power digital TV stations, and 419 Class A low power digital and analog TV stations in the continental U.S., with information on the

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[18] The use of the forward auction to determine the quantity purchased in the reverse auction has the advantages that come from being able to compare the prices in the two auctions—in particular being able to avoid buying the last megahertz of spectrum from broadcasters for more than that megahertz sells to wireless. However, it has the disadvantage of added complexity for all parties—buyers, sellers, and the FCC. Consequently, it may be more practical to use a two-stage process in which the reverse auction is completed before the forward auction is conducted. Since our estimates of positive net proceeds from the two auctions are robust our analysis suggests that such a two-step process could be conducted with reasonable efficiency.

[19] See Index of Media Bureau CDBS Public Database, http://www.fcc.gov/mb/databases/cdbs/ (last visited March 18, 2011).

broadcast channel, location (latitude and longitude), and call-sign for each station.[20] For each station, we determined the channel separation distance requirements based on the Electronic Code of Federal Regulations. In Section VI we examine the impacts of relaxing these (and the international) separation criteria.

We do make an exception to these interference restrictions for individual pairs of stations that currently violate these channel separation distances. On a pair-wise basis, if two stations currently violate co-channel separation restrictions, we allow those two specific stations (and only those two specific stations) to continue to violate that same constraint after repacking. We refer to these pairs as "short-spaced." This allows us to identify existing efficiencies in the current network of stations and towers, and preserve this efficiency under repacking. All other channel distance separation restrictions continue to hold for all other U.S. station relationships.

In addition to identifying the locations and channels of U.S. UHF TV stations, we collected information on the protected digital TV stations in Canada, digital and analog stations in Mexico, and fixed land mobile stations.[21] We used the FCC Letters of Understanding to identify protected Canadian and Mexican TV stations,[22] and gathered the fixed land mobile station information from the Electronic Code of Federal Regulations (47 CFR 90 Subpart L).[23] Since these rules do not admit of a simple summary measure of protection, we used a co-channel separation of 249 km and an adjacent channel separation of 145 km, to be conservative.[24] From

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20 From the CDBS data, we isolated TV station records for Class A facilities (low power analog), digital Class A facilities (low power digital), and full power digital TV facilities broadcasting in the UHF range (channels 14-51). We initially identified 1,296 UHF full power digital TV stations, 90 Class A low power digital TV stations and 336 Class A low power analog TV stations. We cleaned this dataset by eliminating all stations where coordinates were either missing or located in U.S. states and territories outside the continental U.S., and any channels listed as higher than channel 51.

21 We took into account the protection rules governed by the FCC's agreements with Canada's Industry Canada, and Mexico's Secretaria De Comunicaciones Y Transportes. Since Canada will complete its shift to digital broadcast in the near future, we ignored any Canadian analog station constraints.

22 See FCC Letter of Understanding with Industry Canada at http://www.fcc.gov/ib/sand/agree/files/can-bc/can-dtv.pdf and FCC Memorandum of Understanding with Secretaria De Comunicaciones Y Transportes at http://www.fcc.gov/ib/sand/agree/files/mex-bc/mex-dtv2.pdf (both last visited March 18, 2011).

23 See GPO Access, Electronic Code of Federal Regulations, http://ecfr.gpoaccess.gov/cgi/t/text/text-idx?c=ecfr&tpl=/ecfrbrowse/Title47/47cfr90_main_02.tpl (last visited March 18, 2011).

24 Specifically, full-power DTV station separations were obtained from Electronic Code of Federal Regulations (47cfr73.623) and Appendix Table A1, below. For low-power station separations, we calculated the average broadcasting contours for existing analog stations with effective radiated power

the FCC's agreements with Canada and Mexico, we obtained the coordinates and broadcasting channels for all protected stations, as well as the separation distance requirements for interference protection. Our records contain 761 Canadian digital TV stations, 75 Mexican digital stations, and 48 Mexican analog TV stations requiring protection. To be conservative, we used the highest separation mandated for each protected station by class.[25] With respect to Mexican stations, we applied the separation mandated by the U.S.-Mexico agreement.[26] The one exception to these border restrictions is that if an existing station violates a Canadian, Mexican or Land Mobile restriction it is allowed to continue to violate the restriction if it is placed on its original channel.

Using this complete set of channel and distance restrictions, we calculated the distance between individual U.S. UHF stations, and the distances between these U.S. stations and Canadian border stations, Mexican border stations, and land mobile stations. On the basis of these distances, we identified all co-channel and adjacent channel restrictions on each U.S. UHF broadcast station. Each of these restrictions must be followed in the repacking analysis below.[27]

To estimate the amount each commercial station would value giving up its UHF broadcast license, we compiled revenue data from BIA/Kelsey on each station.[28] For any commercial station without published revenue, we assumed that revenue was equal to the lowest published revenues of any station in its power class and DMA.[29] In some DMAs, there was no revenue

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(ERP) and antennae height (HAAT) information. The separation distance requirement we used was twice this contour distance. Separation between low-power and full-power stations was assumed to be the average of each station's separation distance.

25 See Table 4.2.1 of the FCC-Industry Canada Letters of Understanding and Appendix Table A2 below.

26 See Tables A and B of the FCC-Secretaria De Comunicaciones Y Transportes Memorandum of Understanding and Appendix Table A3, below.

27 Our analysis is likely conservative because we used simple mileage separation rules. Calculating required separations based on using propagation models and accounting for the effects of terrain would allow tighter repacking in many markets and would reduce the costs of a reverse auction.

28 See BIA/Kelsey, *Investing in Television Market Report 2010,* Chantilly, VA.

29 This assumption is unlikely to be material. The importance of a station's revenues is in calculating its bid, which only determines whether or not the station is chosen to voluntarily relinquish its license. The estimated amount of the payment is determined by the low bid of the broadcaster *not* chosen to relinquish its license. Stations with unknown value are likely to be relatively small and have low-revenue. So long as broadcasters who do not have revenue reported by BIA/Kelsey fall below the cut-off for accepting broadcasters' offers to relinquish their licenses, this lack of data will have no impact on our estimated costs of clearing spectrum.

listed for any low power stations. In these cases, we calculated the revenue as one third the average revenue for full power stations.[30]

To these revenue data, we applied a multiple to estimate the station's value of its current broadcast license. We estimated this spectrum license multiple based on the financial statements of a set of publicly traded corporation whose primary business is broadcasting. Table 1 below lists the publically traded stations we examined. Our multiple is calculated as the weighted average ratio of the market adjusted value of spectrum assets and revenue for these seven corporations. The market adjusted value of spectrum assets is estimated as the value of intangible spectrum assets, plus the difference between market value of equity and total shareholder equity (equivalent to the total book value of equity). This yields a spectrum license multiple of 1.81. See Table 1. This is the multiple we applied to station annual revenues to calculate each station's bid in the voluntary incentive auction. As we explain below, the resulting adjusted spectrum values were the basis for the value-based prioritization for repacking commercial stations and for the estimate of the cost of a reverse auction.[31]

[30] By calculating the average high power and low power revenues for DMA markets with both full power and Class A low power station revenues, we found that the ratio of average full power revenue to average Class A low power revenue was about 3:1.

[31] We ignore any potential tax effects on broadcaster's bidding for several reasons, including that broadcasters have wildly varying financial histories and tax liabilities and Congress may enact special tax treatment of any accounting gains that come from an incentive auction. In fact, if a broadcaster increases its bid to compensate for tax effects, that increase represents money that will take a round trip from the treasury to the broadcaster and then back to the treasury—the increase is not an increase in the true cost to the government although it does change the accounting treatment of the money.

Table 1. Commercial Broadcasters Implied Spectrum Multiple

	Broadcast Company	2010 Revenues	Filing Year for License Value	Net Broadcast License Value as of Filing Date	Book Value of Equity as of Filing Date	Market Value of Equity as of 4/18/2011	Difference in Equity Value	Market Adjusted Intangibles
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
							[6] - [5]	[4] + [7]
		$ Millions		*$ Millions*	*$ Millions*	*$ Millions*	*$ Millions*	*$ Millions*
[A]	Fisher Communications	$176	2009	$37	$155	$263	$107	$145
[B]	Gray Television	$346	2010	$873	$129	$125	-$5	$868
[C]	Nexstar Broadcasting	$313	2010	$127	-$175	$190	$365	$492
[D]	Belo Corporation	$687	2010	$725	$171	$821	$651	$1,376
[E]	Lin TV	$420	2009	$392	-$169	$275	$444	$836
[F]	Sinclair Broadcasting	$767	2009	$52	-$212	$893	$1,105	$1,157
[G]	Entravision	$200	2010	$220	$10	$194	$183	$403
[H]	Total	$2,910		$2,427	-$90	$2,760	$2,850	$5,277
[J]	Revenue Multiple (Market Adjusted Intangibles / 2010 Revenues)							1.81

Sources and Notes

[2] and [6]: Bloomberg. Downloaded 4/20/2011. Bloomberg Current Market Capitalization used for market value of equity, and Sales, Revenue, and Turnover used for revenue.

[A] [3] - [A][5]: Fisher Corporation 2009 Annual Report. License value is the net after impairments value of the broadcast licenses recorded under intangibles, and book value is recorded as Stockholder Equity.

[B] [3] - [B][5]: Gray Television 2010 Annual Report. License value is the net after impairments value of the broadcast licenses recorded under intangibles, and book value is recorded as Stockholder Equity.

[C] [3] - [C][5]: Nexstar Broadcasting 2010 Annual Report. License value is the net after impairments value of the broadcast licenses under intangibles, and book value is recorded as Stockholder Equity.

[D] [3] - [D][5]: Belo Corporation 2010 Annual Report. License value is the net after impairments value of the broadcast licenses recorded under intangibles, and book value is recorded as Stockholder Equity.

[E] [3] - [E][5]: Lin TV 2009 Annual Report. License value is the net after impairments value of the broadcast licenses recorded under under intangibles, and book value is recorded as Stockholder Equity.

[F] [3] - [F][5]: Sinclair Broadcasting 2009 Annual Report. License value is the net after impairments value of the broadcast licenses recorded under intangibles, and book value is recorded as Stockholder Equity.

[G] [3] - [G][5]: Entravision Communication Corporation 2010 Annual Report. License value is the net after impairments value of the broadcast licenses recorded under intangibles, and book value is recorded as Stockholder Equity.

[H]: Sum of [A] through [G] in each respective column.

[J] [8]: [H] [8] / [H] [2].

Since the non-market value likely accounts for a substantial part of educational station values, we cannot make the same estimation for these stations. Further, since they do not have the same financial obligations to act in the best financial interest of their owners as commercial broadcasters do, we could not assume educational stations would participate in the reverse auction for purely financial reasons. We assumed, therefore, that many of these stations would not give up their broadcast license unless there is a solution by which they could continue to broadcast their programming in a similar manner. As discussed further in the following sections, we prioritized these educational stations above commercial stations.

B. Greenfield Repacking

The purpose of this exercise was to determine the *likely* cost of clearing a portion of the broadcast licenses from the band of spectrum they currently occupy. Our intent is not to forecast the actual specific station-by-station outcome of a future incentive auction. Actual bidding by broadcasters in an auction will determine actual costs, but this exercise allows a reasonable, albeit conservative, estimation of those costs. On the basis of the valuations discussed above, we took a two-step approach to our repacking analysis. We built a national repacking algorithm in which channel assignments are constrained by the channel and co-channel interference of neighboring stations, border interference constraints with Canada and Mexico, and land mobile constraints. In this way, our analysis is similar to the FCC's approach.

The major difference between our analysis and that presented in the FCC's OBI Technical Paper 3 is that the FCC analysis set as its objective clearing spectrum by minimizing both the number of stations that would have to relinquish licenses and the number of stations that would have to move.[32] In contrast, we only focused on removing the stations that cost the least to clear a given amount. Thus, if there were a trade off between accepting bids for two licenses in smaller markets against accepting one more valuable license in a larger market, our analysis would accept the bids for the two licenses in smaller markets over the one bid for the more valuable license in a larger market. This is driven by our economic goal of minimizing the cost of repacking, while limiting the number of stations that must give up their license.

In the first step of our analysis, we prioritized stations in the order of importance for preserving their license in the remaining new core of broadcast stations. Stations are prioritized first by type—educational, commercial full power, commercial Class A low power. Within these groups, stations were ranked by DMA and, within a DMA, commercial stations were further ranked by revenue. DMAs were ordered by the cost of clearing,[33] as opposed to the total revenue value of the DMA. Repacking the more costly markets reduces the inter-market interference restrictions in those markets and minimizes the number of stations that must relinquish their existing UHF licenses in the most expensive markets.[34] We elaborate on the prioritization of stations below:

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32 See OBI Technical Paper No. 3 2010 at p. 48.

33 We derived the cost of clearing order by first repacking all stations, ordering the commercial UHF stations strictly by value, without consideration of market. Using these results, we ordered the DMAs from most expensive to clear to least expensive to clear.

34 We made a few exceptions to the ordering described, by increasing the priority of some of the stations in Hartford, Detroit and San Diego.

- *Educational stations.* We identified a small number of educational stations that would likely participate in an incentive auction. We assumed that educational stations that broadcast in close proximity to each other would have an incentive to relinquish one license, share a signal and continue their existing missions, covering the same audience. The licensee that relinquished its license would receive significant revenue from the auction and enjoy ongoing cost savings from not having to operate a transmitter. That source of revenue could be used to compensate the continuing broadcaster to use its secondary signal(s) to broadcast the programming stream of both educational broadcasters. As a consequence, both broadcasters could receive significant revenue in exchange for giving up the programming on their secondary broadcast channels. To identify these candidate broadcasters, we first selected all sets of educational stations that broadcast within 10 miles of each other and then reviewed them individually to determine which one was more likely to continue broadcasting. (For example, if one was a low power and one a full power broadcaster, the full power broadcaster would be selected to continue broadcasting.) We also assumed that in 19 markets with substantial numbers of educational broadcasters, at least one additional station would participate.[35]

  Repacking the remaining educational stations was our first priority. To determine the order by which they are repacked, we grouped the stations by DMA and ranked the DMAs in order of highest to lowest cost to clear. See footnote 30.

- *Commercial high-power UHF stations.* The next prioritization of stations was for the high-power commercial UHF stations. First, these stations were grouped by DMA. Within each DMA, the stations were ordered from highest to lowest value. Such an ordering ensures that the highest valued stations are placed on the lowest available channels. The DMAs were then ordered from highest-cost-to-clear to lowest-cost-to-clear. See footnote 30.

- *Low power Class A UHF stations.* Finally, Class A low power stations were ordered by the same DMA ranking as used for the full power commercial UHF stations. Within each DMA, stations with known revenue were ordered from highest to lowest first, followed by all additional stations in arbitrary order.

Second, each station was assigned a channel on its existing tower in order of the priority list. In placing each station, the algorithm looks for the lowest available channel on the tower and then checks that channel for the appropriate co-channel restrictions; adjacent channel restrictions; and Mexican, Canadian, and land mobile restrictions. If all of the constraints were met, then the station was placed on that channel on that tower; otherwise, the process was repeated for the next available channel on that tower.[36] If a pair of stations is part of a short-spaced pair and the other

35 Our selection was based on a preliminary analysis in which we identified 19 relevant markets where there were at least 3 full power stations remaining after repacking. In each of these markets, we assumed one educational station would participate in the auction.

36 If a station could not be assigned channel 51 or below, and if the channel that station is currently broadcasting violates only the Mexican, Canadian, and land mobile restrictions, then the station was

station in the pair is already placed, then the algorithm will allow the station to be placed on that channel if all surrounding constraints are met.

From this two-step process we can identify the total number of full power and Class A low power UHF commercial broadcasters and educational stations to be compensated to relinquish their UHF broadcast license in order to clear any given bandwidth of spectrum. Similarly, we calculated the number of stations that must move channels—and be compensated—although they remain on the same tower broadcasting to the same service area. For the purposes of our analysis, we considered the number of moved channels and returned licenses required to clear 120 MHz, 102 MHz and 84 MHz. Table 2 below presents the number of broadcasters required to relinquish their current UHF licenses to clear various amounts of spectrum.

C. CALCULATION OF CLEARING COSTS

Our estimate of the total payments that will be made to broadcasters who relinquish their licenses is based on the approach that every broadcaster would be paid the value of the lowest bid not accepted in the auction. Put differently, each broadcaster who gives up its license would be compensated at the level of the bid from the lowest valued broadcaster remaining in the market. For example, if 5 broadcasters were to bid $10 million, $12 million, $15 million, $18 million, and $24 million and on the basis of those bids 2 were chosen to relinquish their UHF broadcast licenses, the 2 lowest bidders would receive $15 million each, because $15 million would be the lowest bid of the broadcasters whose offers to relinquish their licenses were not accepted.[37]

Assuming broadcasters bid truthfully (which would be expected to occur if the auction is properly designed and there are sufficient excess bidders), we estimate that each broadcaster's bid should be equal to their market adjusted spectrum value. When compensated their market adjusted spectrum value, commercial broadcasters should be indifferent between continuing operations and giving up their license. Since relinquishing a current UHF license does not

reassigned to its current broadcasting channel. This implicitly assumes that, if a station currently violates a border or land mobile restriction, that restriction can continue to be violated under repacking.

[37] Note that there are cases where lower valued stations can be repacked where higher valued stations were constrained. Consequently, there are a handful of markets where the highest valued broadcaster would be selected to return their current UHF license. In any case where the highest revenue station must return its license, we assume the payment is equal to the highest broadcaster bid.

necessarily imply that a broadcaster would stop broadcasting, this is a conservative estimation of their bids. To determine this marginal value of the last full power station left in the market, we used the BIA/Kelsey revenues, as discussed in Section IV.A, above.

The educational stations identified as likely to participate in the auction were assumed to bid an amount below the market clearing price so that they are included in the broadcasters selected to relinquish their licenses. If a single price is paid to all accepted broadcaster bids in a market, educational broadcasters would still receive the market clearing price, regardless of their bid. It is worth noting that, unlike commercial full power UHF broadcasters, an educational station participating in the auction would tend to have a cost-reducing effect on total clearing costs in a market. Each additional educational station willing to relinquish its license implies one less commercial broadcaster that must give up its license. Since the lowest valued commercial station left in the market determines the market clearing compensation, the fewer commercial stations required to give up a license, the lower the cost of compensation to all. In fact, extra inducements for public broadcasters to participate in the auction, such as a bonus payment in addition to the market clearing price paid to all existing broadcasters, could actually reduce total clearing costs.[38]

Repacking TV stations in the UHF band should not impose significant burdens on broadcasters or the public. Indeed, under reasonable assumptions, repacking should leave broadcasters with better facilities and equal or better coverage than they had before repacking. The costs of repacking should be relatively small compared to the costs of compensating broadcasters in order to encourage them to return their current UHF licenses.[39] After repacking, most remaining UHF broadcasters will be on lower channels than before. It is generally accepted that lower UHF channels provide better coverage for TV broadcasting. Additionally, to the extent that changing

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[38] For example, suppose a market needed six full-power broadcasters to exit, the seventh lowest bid was for \$70 million, and the sixth lowest bid was for \$60 million. If a public broadcaster entered the bidding in this market, the impact on clearing costs would be to lower the price paid per license from \$70 million to \$60 million, a savings of \$10 million for each of the six full-power licensees exiting or \$60 million in total. Even if the public broadcaster were paid a bonus payment of \$30 million to participate, total clearing costs in the market would still decline by \$30 million.

[39] It is worth noting that if broadcasters had the option to stay on their original channel, the costs of clearing spectrum would be much higher. Consequently, the repacking is mandatory, but with compensation. Participation in the incentive auction is completely voluntary.

frequencies requires new transmitting equipment, the broadcaster receives an equipment update or upgrade at no cost to the broadcaster.

We estimated the cost of repacking UHF stations by considering the costs of building a UHF transmitting facility as reported by NTIA.[40] Rather than assuming that moving a UHF station to a different channel would require complete replacement of a station's transmitting facility we assumed that, worst case, only the transmitter's power amplifier stage, the transmission line from the transmitter to the antenna, and the antenna would require replacement. Whether these facilities would require full or partial replacement will vary from case to case. A broadcaster moving from channel 28 to channel 27 may be able to reuse the existing antenna and transmission line and may be able to have the transmitter modified at relatively little cost. In contrast, a broadcaster moving from channel 51 to channel 14 may require a new antenna, a new transmission line, and substantial transmitter modifications.

We estimated the average cost of moving a TV station from one frequency to another by considering the maximum costs for transmitters, antennas, and feed lines for full power and low power TV stations in the NTIA data. Based on examination of the transmitter cost figures in the NTIA data, we calculated that \$350,000 of the cost of a TV transmitter included elements that would not require changing but that the remaining cost (\$40,000 for a low power station and \$600,000 for a full power station) might require full or partial replacement. We then split the difference—essentially assuming the number of stations requiring an upgrade that cost one-quarter of the maximum possible was matched by the number of stations requiring an upgrade that cost three-quarters of the maximum possible. We then added in a payment to the broadcaster of 15% of the costs of the equipment and installation charges to account for managing the process and the time value of money between any expenditures and reimbursement. See Appendix Table A4.

The result of this calculation was an estimate of \$885,500 for the average cost of repacking a full power station and \$267,375 for the average cost of repacking a low power station. The details of our calculation are shown in Appendix Table A4. Our results are not sensitive to the cost of

40 See http://www.ntia.doc.gov/ptfp/application/EquipCost_tv.html (last visited April 22, 2011).

changing a broadcaster's broadcast channel as these costs account for around 5% of the cost of clearing 120 MHz. Doubling that amount will not qualitatively change our conclusions.

D. Results

Table 2 below summarizes the results of our analysis for clearing the targeted amounts of spectrum. Our results suggest that it could cost up to $15.2 billion to clear a continuous band of 120 MHz from the television broadcasters' band. Most of this cost (approximately $14.4 billion) is based on the compensation necessary to induce broadcasters to give up their spectrum. The cost of moving existing stations is under $0.78 billion. The cost of clearing more narrow increments of spectrum is considerably lower. For instance, under our analysis, clearing 102 MHz of spectrum costs around $11.6 billion and the cost of 84 MHz is about $8.2 billion.

One concern with the clearing cost estimation approach we use is that stations that return their license may receive compensation potentially well above their actual bids. To clear larger amounts of spectrum—108 MHz or 120 MHz—the ratio of the total payments to the sum of the accepted bids is around 3.5. In addition to encouraging broadcasters to enter the auction, as discussed above, paying each winning bidder the marginal bid value will incentivize broadcasters to bid the value of their spectrum truthfully. In turn, truthful bidding will avoid a hold-out problem in the auction.

Table 2. Cost of Greenfield Repacking of UHF Stations

MHz Cleared	Total Cost of Clearing *$ Millions* [1]
120 MHz	15,220
102 MHz	11,634
84 MHz	8,166

Source: The Brattle Group Analysis.
[1]: Includes cost of both stations returning licenses and stations moving channels.

V. AUCTION REVENUE

Given the total cost of clearing up to 120 MHz of spectrum or more from broadcasters, the next question is: "What would be the revenues from auctioning that spectrum?" In order to estimate the value of this potential spectrum at auction, we can rely on the known values of comparable, existing spectrum licenses. The current broadcast spectrum that would be recovered is located in the 500–600 MHz band, adjacent to the 700 MHz spectrum. The FCC auctioned the 700 MHz spectrum in March 2008. For the purposes of this analysis, we assumed the FCC develops a well-designed, unconstrained auction with results similar to the 700 MHz band auction.[41]

In March 2008, prior to the economic downturn, the average price of the A, B, and C blocks was \$1.36 per MHz-Pop. See Table 3. Estimates from the Spectrum Bridge Spectrum Index suggest the current value of spectrum is likely 1% lower now than three years ago.[42] As illustrated in Table 3, this suggests that the updated spectrum value is \$1.35 per MHz-Pop presently.[43]

Since we are potentially introducing up to an additional 120 MHz of spectrum, we must consider the impact of increasing the supply of spectrum by up to 19%. As Table 4 shows, there is currently the potential for up to 645 MHz of value weighted 700 MHz equivalent spectrum to be available for licensed broadband use. The value weighting is approximate and intended to capture the relative importance of a band to the overall supply of spectrum. The value weights are all relative to the value of 700 MHz spectrum. For example, bands that are lower in frequency and more established tend to have greater weight than higher frequency or newer allocations. Adding an additional 120 MHz of spectrum similar to the 700 MHz band would increase the total available spectrum by about 19%. Based on previous estimates, the elasticity

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41 There are reasons to believe that the realized value of the 700 MHz auction understated the real value of that spectrum, suggesting the current estimates may be conservative. See Bazelon, "Too Many Goals," 2009.

42 This valuation is done as of July 25, 2011, a date prior to the recent, and presumably transient, stock market volatility.

43 We do not believe that the recently announced merger of AT&T and T-Mobile would significantly change underlying spectrum values. Spectrum values are driven by the long-term balance of supply and demand, neither of which are fundamentally changed by the proposed transaction. One important factor driving the value of wireless spectrum is the cost of cell-splitting. At the margin a wireless operator that needs to expand capacity can choose between buying more spectrum or using its existing spectrum more intensely. That trade-off defines an implicit marginal value (shadow price in economist's jargon) for spectrum underlying the marginal value at auction and resulting price. For more discussion of this tradeoff see FCC "Benefits of Broadband," 2010, pp. 20 – 26.

of spectrum is likely about -1.2,[44] implying that the price would decrease to about $1.17 per MHz-Pop. This suggests that the total revenue would be $40.0 billion for an additional 120 MHz of spectrum. Auctioning as few as 80 MHz of spectrum implies a spectrum value of $1.21 per MHz-Pop and $29.1 billion in total revenue.

[44] See discussion in Bazelon, Coleman, "Analysis of an Accelerated Digital Television Transition," May 31, 2005, citing Ingraham, Allen T. and Gregory Sidak, "Do States Tax Wireless Services Inefficiently? Evidence on the Price Elasticity of Demand," 24 Virginia Tax Review, 2004 (Herein "Ingraham and Sidak (2004)"). More recent research also suggests that a price elasticity for wireless telephony between -1.12 and -1.29 is appropriate see Hazlett and Munoz (2009). This elasticity is also consistent with recent broadband price elasticity estimates between -1 and -1.5. See Crandall and Singer (2010).

Table 3. Estimated Value of Broadcast Spectrum for Wireless Use*

			March 18, 2008 [A]	July 25, 2011 [B]		
[1]	SpecEx Index Values		300	297		
[2]	SpecEx Implied Change in Spectrum Value	%		-1%		
[3]	U.S. Population	Pop	285,620,445	285,620,445		
[4]	700 MHz Spectrum Value for A, B and C Blocks	$/MHz - Pop	$1.36	$1.35		
[5]	Estimated Elasticity of Spectrum Demand			-1.2		
[6]	Current 700 MHz Equivalent Spectrum Supply	MHz		645		
				120 MHz Block	**102 MHz Block**	**84 MHz Block**
[7]	Additional Spectrum from Broadcast Block	MHz		120	102	84
[8]	Percent Increase in Spectrum Supply from Broadcast Block	%		19%	16%	13%
[9]	Estimated Value of 600 MHz Spectrum for Broadband	$/MHz - Pop		$1.17	$1.19	$1.21
[10]	Total Estimated Value of 600 MHz Spectrum for Broadband	$		$39,996,024,276	$34,677,925,571	$29,144,713,180

Sources/Notes:
* Analysis assumes clearing costs and encumbrances similar to 700 MHz A, B and C blocks. Additional costs or restrictions would lower the value. Currently UHF broadcast spectrum runs from 470 MHz - 698 MHz. Analysis assumes clearing the top 120 MHz, for instance 578 MHz - 698 MHz, for wireless broadband.
[1][A] & [1][B]: Spectrum Index (TM) at Spectrum Bridge, http://spectrumbridge.com/products-services/specex/index.aspx (last visited July 25, 2011).
[2][B]: [1][B]/[1][A] - 1.
[3][A] & [3][B]: Population used by FCC in Auction 73, http://wireless.fcc.gov/auctions/default.htm?job=auction_summary&id=73 (last visited March 1, 2011).
[4][A]: Results from Auction 73 include the average price per winning bid for the A, B, and C blocks.
[4][B]: [4][A]*(1 - [2][B]).
[5][B]: Bazelon, Coleman. "Analysis of an Accelerated Digital Television Transition," White Paper sponsored by Intel, May 31, 2005.
[6][B]: Current U.S. Liberally Licensed Radio Spectrum calculated based on Table 4.
[7]: The Brattle Group assumption.
[8]: Value based on approximate value weight of band. TV Broadcast spectrum assumed to be equal to the 700 MHz band weight of 1.25.
[9]: [4]*([8] + 1)^(1/[5]) for each potential sized spectrum block.
[10]: [3][B]*[7]*[9] for each potential sized spectrum block.

Table 4. Available Licensed Radio Spectrum for Broadband

	Band Name	Location	MHz	Assigned	Potential Spectrum Supply	700 MHz Value Weight	700 MHz Equivalent Value Weighted Potential Spectrum Supply
			[1] *(MHz)*	[2] *(%)*	[3] *(MHz)*	[4] *(Index)*	[5] *(MHz)*
[A]	PCS	1.9 GHz	130	100%	130	2.3	298
[B]	Cellular	800 MHz	50	100%	50	2.3	115
[C]	SMR	800 MHz / 900 MHz	14	100%	14	0.8	11
[D]	BRS/EBS	2.5 GHz	174	100%	174	0.4	66
[E]	AWS-1	1.7 GHz / 2.1 GHz	90	100%	90	0.8	69
[F]	700 MHz	700 MHz	80	88%	70	1.0	70
[G]	ATC Spectrum	1.5 GHz / 2 GHz	88	50%	44	0.4	17
	Total		626		572		645

Notes:
[3]: [1] * [2]
[A] [4] - [G] [4]: TBG calculation
[5]: [3] * [4]
Sources:
[A] [1]: Congressional Budget Office, Where Do We Go From Here? The FCC Auctions and the Future of Radio Spectrum Management, (Apr. 1997)
Improving Public Safety Communications in the 800 MHz Band, Report and Order, Fifth Report and Order, Fourth Memorandum Opinion and Order, and Order, 19 FCC Rcd 14969 (2004)
[B] [1]: FCC Wireless Telecommunications Bureau, Cellular Services, available at http://wireless.fcc.gov/services/cellular/
[C] [1]: FCC Wireless Telecommunications Bureau, 900 MHz SMR, available at http://wireless.fcc.gov/smrs/900.html
[D] [1]: FCC Wireless Telecommunications Bureau, BRS & EBS Radio Services, available at http://wireless.fcc.gov/services/brsebs/
[E] [1]: Amendment of Part 2 of the Commission's Rules to Allocate Spectrum Below 3 MHz for Mobile and Fixed Services to Support the Introduction of New Advanced Wireless Services, Including Third Generation Wireless Systems, Second Report and Order, 17 FCC Rcd 23193 (2002)
[F] [1]: Revised 700 MHz Band Plan for Commercial Services (2007) includes D block and is available at http://wireless.fcc.gov/auctions/default.htm?job=auction_summary&id=33
[F] [1]: FCC Wireless Telecommunications Bureau, 700 MHz Guard Bands, available at http://wireless.fcc.gov/services/index.htm?job=service_home&id=700_guard
Supply is equal to the band plan's total allocation, including D Block, less 700 MHz guard bands
[G] [1]: The bandwidth includes the licensed MSS spectrum holdings of MSV (28 MHz), TerreStar (13.3 MHz), and ICO Satellite Services (13.3 MHz). See, W.P. Zarakas and K. Wallman, "The Brattle Group Report," October 5, 2005, contained in Motient Corp. June 2, 2006 SEC Form DFAN14A (filed June 2, 2006), via Edgar, accessed October 2009.

VI. ROBUSTNESS OF RESULTS

As with any estimate or projection, our estimates of the cost of clearing broadcast spectrum are subject to a variety of factors that render those estimates less than perfect. Factors that may have a significant impact on the estimates herein include the following:

- Market adjusted spectrum value and broadcaster valuation,
- Possible strategic behavior by broadcasters in a reverse auction, and
- Our auction forecasting approach.

Below we address each of these in turn. Our analysis also considers the cost of moving stations from one channel to another. However, as noted above, that cost is a small fraction of the total cost: thus, even relatively large errors in the cost of moving stations will have little impact on our results.

A. MARKET ADJUSTED SPECTRUM VALUE AND BROADCASTER VALUATION

The use of a multiple of station revenues as a proxy for market adjusted spectrum value was discussed in detail earlier. With respect to the income-based approach, any error in the multiplier used to translate revenues into spectrum value results in proportionate errors in the estimated value. Our 1.81 spectrum value multiple is a reasonable estimate of clearing costs.[45]

It is possible that a broadcast station owner may place a higher value on its spectrum license than the adjusted spectrum license value as objectively calculated. For example, a broadcast station may be a family business or management may derive great satisfaction from their role as an important community resource and employer. Similarly, some Class-A station operators may be motivated to serve particular audiences and needs rather than simple profit maximization.

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[45] Comparing our estimate of total enterprise value multiples with those of CTIA/CEA and FCC suggest that our sample of broadcasters (see Table 1) is also reasonable. Our estimate of an enterprise value multiple is 2.5, which falls in the middle of the range of enterprise multiples 1.6—used by CTIA/CEA—and 3.57—used by the FCC. See CTIA/CEA 2011, p. 14. The CTIA/CEA study also factor in a 7% increase to gross revenues, which implies a multiple range of 1.28 – 2.14. See, also, OBI Technical Paper No. 3 2010, footnote 12, the FCC's 3.57 multiple is calculated as the average operating margin of 35% times the average EBITDA multiple of 10.2.

Although such non-monetary values may influence some broadcasters, we believe that it is unlikely that they would strongly influence enough of the owners of the lowest-revenue TV stations in a market to significantly change the outcome of the reverse auction. In our estimation of payments to broadcasters, if the lowest revenue stations—those most likely to be influenced by the non-market considerations—bid above their market adjusted spectrum value it is unlikely to alter the outcome of the auction because so long as they are bidding below the marginal licensee, their changed bid does not alter who is selected to relinquish their license or the amount they are compensated.

As noted above, broadcasters who return their license still have many options for continuing to distribute their programming, including possibly moving to a VHF channel, co-broadcasting with another broadcaster, altering their service area or distributing their programming directly over cable or satellite. All of these alternatives are very realistic for broadcasters. Some broadcasters use the VHF frequencies and there are many unused VHF channels available.[46] Multicasting is common today and with the right incentives provided by the proposed incentive auction the multiple streams of programming could include more than one primary broadcast signal. In fact, WBOC in Salisbury, MD broadcasts in high definition programming from both CBS and Fox.[47] If this model was expanded, the top four networks could be broadcast over-the-air on just 2 full-powered signals. Consequently, considering the various offsetting effects, we believe that using the estimated adjusted spectrum value provides the most robust estimate of the value that a broadcast station owner would bid to relinquish their current UHF broadcast license.

B. POSSIBLE STRATEGIC BEHAVIOR BY BROADCASTERS IN A REVERSE AUCTION

It is possible that broadcasters choose to hold out for more than the minimum price they are willing to accept. Broadcasters would submit the bid that they think would be best for them, taking into account their own valuation and their estimate of what bid the FCC would accept. If broadcasters could collude, for instance by agreeing in advance that they all would ask the FCC for twice what they are willing to settle for, then the auction would select the same set of

[46] We did not do an analysis of repacking broadcasters on VHF channels, but undoubtedly many would be able to find a channel in the VHF frequencies. Note that there are 12 VHF channels (2 – 13) and less than half of these are used in any top 30 market, except Denver Colorado where there are 7 VHF stations.

[47] OBI Technical Paper No. 3, pp. 18 – 19. See also WBOC's own website at http://www.wboc.com.

broadcasters to relinquish as in a non-collusive auction (assuming forward auction receipts were still sufficient to cover these costs), but the payments to the broadcasters would be twice those that would occur without collusion. Such collusion would be difficult to enforce because some broadcasters whose bids would not be accepted would have an incentive to defect from the collusive agreement and bid their true value.[48] The solution to avoiding such collusion is strict and enforceable anti-collusion rules, which the FCC has substantial experience creating and enforcing. The risks of being caught colluding in an FCC auction may be high. The FCC could conceivably find that a violating broadcaster was not fit to hold a broadcast license.

Another concern is that a broadcaster would bid for a buy-out by asking more than the minimum that the broadcaster would actually accept. There is no doubt that the broadcaster would like to get as much as possible. The FCC can design an auction that likely gives the bidders the incentive to bid honestly. One way to do this is to ensure that the amount of compensation received by each licensee whose offer is accepted is not the amount of the offer, but rather is the amount of the lowest offer that was not accepted. Such an auction—known as a Vickery or second-price auction—has the desirable feature that bidders' best strategy is to bid their actual valuation.[49]

If bidders put in a bid for more than they are willing to accept to relinquish their license in a Vickrey auction, they may find that their offer is rejected, but the price paid to the accepted bidder is higher than the price they would have been willing to accept. Likewise, they have no incentive to bid less than their true valuation because they risk having their bid accepted but not receiving sufficient compensation. Moreover, if their bid is chosen, the amount that they bid does not directly influence their payment—rather that payment is determined by the amount the next higher broadcaster offered to accept to relinquish their license. The FCC has substantial experience with auctions, having now held almost one hundred auctions involving total revenues exceeding $50 billion. We are confident that the FCC can design an auction that will be as

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[48] This would be true for any broadcaster whose value was between the non-collusive market clearing price and the collusive market clearing price. Although a defector from the collusive equilibrium would be easily found out when the auction results were announced, this is a one-shot game, making discovery of defection less important.

[49] See Lawrence M. Ausubel and Peter Cramton, "Vickrey Auctions with Reserve Pricing," *Economic Theory*, 23, 493-505, April 2004.

competitive as is reasonably possible and that will result in bids that lead to an outcome close to that of a second-price auction.

Of more concern than the quality of the auction design is the possibility that there will not be sufficient broadcasters in some markets to create enough demand in the auction to effect a competitive market price. As discussed above, in order to create the proper incentives for bidders to bid their valuations truthfully, there must be sufficiently more bidders than bids. If broadcasters knew that the FCC had to remove every station from a market, then each broadcaster could submit a very high bid. This, however, is unlikely to happen. In order to clear 120 MHz of spectrum, our analysis suggests that at a minimum between 4 and 20 full power broadcasters will continue broadcasting in their current UHF or VHF band in each top 30 market. In fact, there are likely to be many more than 4 stations remaining in most top 30 markets.

Furthermore, many more than that minimum will likely continue broadcasting as broadcasters find VHF channels, co-broadcast or alter their service areas. As the amount of spectrum to be cleared decreases, the number of excess competitors in most of these markets increases. Also, as long as the FCC has the flexibility to not clear certain hold out markets, the power of the potential hold outs would be greatly reduced. Reducing the amount of spectrum cleared in one or more markets will mean that there is not the same amount of spectrum cleared nationally. This will no doubt reduce auction receipts, but the reduction in receipts could be more than compensated for by reduced payments to broadcasters. If educational stations choose to return their UHF spectrum licenses then, as discussed above, there will be additional competition that is also likely to reduce the marginal spectrum value for auction. Importantly, as also discussed above, markets are interconnected because of overlapping interference restrictions so that the ability to substitute stations from adjacent markets further mitigates potential hold out power.

In most markets, the income data indicate that the major broadcast affiliate stations have the highest revenue and spectrum license value. Consequently, in most markets our model predicts that these stations will not be bought out. In very few markets, our model predicts that fewer than four commercial stations may remain on the air in the UHF band. In those markets where we predict a smaller number of commercial stations, there are two possibilities to support more broadcasters generally, and major network affiliates particularly. First, as mentioned above, there may be an opportunity for one or more stations to move to the VHF band. Second, as the Salisbury, MD example above demonstrates, modern digital technology allows two stations to share the same over-the-air signal. Thus, even if only 4 full power broadcasters remain in a market, there may still be the opportunity for 8 over-the-air broadcast "stations."[50]

In most markets, the revenue distribution of broadcasters suggests that the auctions will be competitive. Although the lowest revenue stations in the larger markets do not value their spectrum licenses equally, it is the case that the spectrum license values of the lowest revenue stations are not widely disparate.[51] Figure 1 plots the relative value of stations in the top-ten markets. The station revenues are all normalized so that the most valuable station in each market is assigned the relative value 1.0 and other stations are assigned a relative value equal to the ratio of the station's revenue to the revenue of the most valuable station in its market. The plots for all ten markets are similar—the top five to eight stations are quite valuable, but after that value trails off and there are not large differences in value between the tenth- and twelfth-ranked stations. If the twelfth-ranked station were to choose to bid unrealistically high, then its place could be taken by the eleventh-ranked station without significantly changing the outcome.

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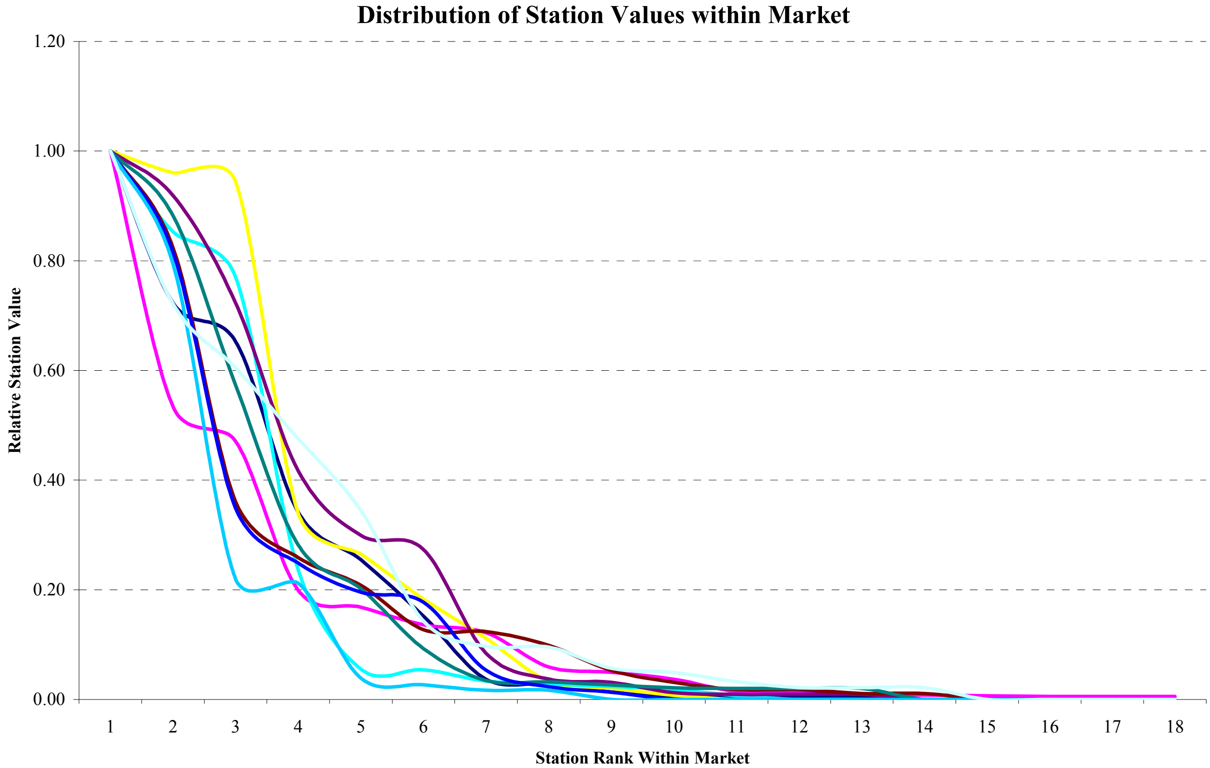
50 See footnote 46 for further discussion on available stations in the VHF band.

51 Because we are estimating spectrum license value as a multiple of station revenues, the ranking of stations by revenue or estimated spectrum license value are congruent.

Figure 1. Relative Station Revenues in the Top Ten Markets as a Function of Station Rank



Source: http://www.fcc.gov/ftp/Bureaus/MB/Databases/cdbs/. Also, BIA/Kesley. Investing in Television Market Report 2010.

C. OUR AUCTION FORECASTING APPROACH

The algorithm we used cleared the band by removing the least valuable stations. The algorithm was a heuristic one that probably performed slightly less well than would an optimal algorithm based on integer linear programming such as used by the FCC. The benefit of the heuristic algorithm is that it ran quickly enough to experiment with many different approaches.

As discussed above, the value of stations in a market does not vary sharply with the station's rank over much of the lower distribution—the fifth most valuable station in a market has a similar value as the fourth most valuable or the sixth most valuable. If our estimate of the number of stations whose offers to relinquish their current UHF license are accepted is off by one, the costs would be higher or lower than we estimated, depending on whether it is one more or one fewer. However, because the difference in expected bids between any two stations whose revenues and spectrum values are similar is relatively small in many markets, the error in estimating costs is limited in many markets. The total cost of all buyouts would be unlikely to rise sharply if it turns out that we have slightly underestimated the number of stations in a few markets that must be removed to clear a given amount of spectrum.

The packing of disks on an infinite plane provides a mathematical analogy to the problem of assigning television channels to cities.[52] Studies of the packing of disks in the plane have shown that the tightest packing can hold about twice as many disks as can a purely random packing in which disks are randomly dropped into vacant spaces in the plane.[53] We believe that our heuristic algorithm, while not optimal, is substantially better than a random packing. If we assume that it functions only two-thirds of the way between random packing and the tightest possible packing, then we would expect it to achieve a packing that is about 85% as good as the best possible packing. Thus, although an optimal packing algorithm would result in a tighter packing and a somewhat lower cost, we have reason to believe that the difference between our (over) estimate of the cost of repacking and a more precise estimate would be relatively small.[54]

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52 This analogy is limited. In the case of television stations, we know in advance the locations at which we wish to place stations (disks) and the stations have an associated value. Nevertheless, this analogy is instructive.

53 Gauss showed that in the tightest possible regular packing of disks in the plane is the hexagonal array, which covers 91% of the area of the plane, and Toth showed that it was the densest of all possible disk packings. See http://mathworld.wolfram.com/CirclePacking.html. Simulation results of a random packing (available from the authors) that continues to place disks on the plane until there is no more room for one to fit covers about 0.492 of the area of the plane or about 55% of the area covered by the densest packing.

54 Of course, the potential over estimate of clearing costs based on broadcasters bidding lower than their adjusted spectrum value remains.

D. IMPACT OF USING STRICT STATION SEPARATIONS

As noted, our repacking analysis adheres to the strict separation requirements as outlined in FCC rules. By using these conservative separation requirements, we assure that no viewers would lose service that they currently receive. But this conservatism comes at a significant cost. By allowing some small reduction in broadcaster service area, television stations could be repacked closer together, which would increase the number of broadcasters that could continue broadcasting post-repacking. The tighter packing would also reduce the payments to broadcasters, as fewer of them would be paid to relinquish their UHF license.

To determine the cost of this conservatism, we performed a second repacking analysis in which we reduced all station separation distances by 10%. The results are reported in Table 5. For clearing 120 MHz, reducing station separations by 10% saves an estimated $2.5 billion and allows an additional 83 stations to remain on the air.

Table 5. Cost of Clearing for Strict and Relaxed Station Separation

MHz Cleared	Total Cost of Clearing			Stations Saved
	Strict Separation	Relaxed Separation	Difference	
	$ Millions	*$ Millions*	*$ Millions*	
	[1]	[2]	[3]	[4]
120 MHz	15,220	12,758	2,462	83
102 MHz	11,634	8,285	3,349	77
84 MHz	8,166	4,952	3,214	64

Sources and Notes: The Brattle Group Analysis.
[3]: [1] - [2].

E. BROADCASTER COMPENSATION VERSUS BROADCASTER CONTRIBUTION

The analysis in this paper estimates the amount of compensation broadcasters would likely receive assuming the incentive auction were designed to give broadcasters the incentive to truthfully reveal the compensation needed for them to relinquish their UHF license. This compensation approach raises at least one issue—how much of the value of their spectrum for wireless broadband use are broadcasters receiving? Based on the percentage of total auction revenues broadcasters receive, they are garnering between 28% (if 80 MHz is reallocated) and 38% (if 120 MHz is reallocated) of expected auction revenues.[55] But this measure is misleading, because a significant amount of the auction value is based on the white spaces that the TV broadcasters are not currently using.

For this paper we recently calculated the share of the expected auction receipts that are associated with the white spaces in the TV band. To do this, we calculated the MHz-pops in each CMA that are currently white space. Next, we valued these MHz-pops on a CMA adjusted basis.[56] The results are reported in Table 6. The white spaces account for between 33% and 35% of the expected auction receipts. When adjusted to reflect the contribution of value of the broadcast stations to the auctioned spectrum, the compensation broadcasters receive is between 27% and 56% of the value their spectrum adds to the auction.

Table 6. Value of White Space Compared to Broadcaster Compensation

MHz Cleared	Value of White Space [1]	Value of White Spaces as % of Auction Revenue [2]	Value of Non-White Space [3]	Broadcaster Compensation as % of Non-White Space Value [4]
120 MHz	13,045,398,553	33%	26,950,625,723	56%
102 MHz	11,313,665,491	33%	23,364,260,080	50%
84 MHz	9,591,753,848	33%	19,552,959,333	42%

Notes:

[1]: The Brattle Group Analysis.

[2]: [1] as a percentage of estimated auction revenue receipts from Table 3.

[3]: The difference between estimated auction revenues from Table 3 and [1].

[4]: Total cost of clearing from Table 2 as a percentage of [3].

An alternate way to view this computation is to identify the loss from the current allocation of spectrum to broadcasting as consisting of two parts—the loss of the idle "white space" spectrum and the loss created by the less efficient use of the spectrum actually occupied by the

[55] These percentages can be calculated from Table 8, below.

[56] We calculated the CMA $/MHz-pop value by adjusting the national average $/MHz-pop value of the auctioned spectrum by the ratio of the CMA $/MHz-pop value to the band average value of the Lower 700 MHz B Block in 700 MHz auction.

broadcasters under the current broadcast rules. Our analysis indicates that this loss splits about one-third for the white space and two-thirds for the less efficient broadcast use.

F. MULTIPLE AUCTIONS: LOWER BROADCASTER COMPENSATION AND HIGHER AUCTION REVENUES

Reallocating TV broadcast spectrum in one auction is also advantageous to broadcasters and reduces expected auction receipts, because it maximizes the compensation they receive. For the same amount of spectrum, if the bids to relinquish the UHF licenses were evaluated in three separate auctions, the number of broadcasters required to relinquish their license would be lower in each auction. As a result, the marginal bidder in the first two auctions would have a lower value for its spectrum license than in the single auction scenario. In turn, the market clearing price for the first two auctions would also be lower than the single market clearing price from one auction. Total payments to broadcasters over all three auctions would be lower. In the example illustrated in Table 7 of the impact clearing 120 MHz over 3 auctions of 40 MHz each, the total cost of clearing over all three auctions is $11.7 billion, a reduction in total payments to broadcasters of $3.5 billion.

At the same time, a single auction approach also raises less revenue for wireless broadband spectrum than 3 properly spaced auctions. In a multiple auction format, only 40 MHz of spectrum would be released in each auction. As discussed above, the price elasticity of wireless broadband spectrum is around -1.2. This implies that a 1% increase in the base supply of spectrum should result in a 1.2% decrease in the equilibrium price of spectrum. The relevant base supply of spectrum includes all spectrum currently allocated to wireless broadband uses and assigned to a licensee, as well as spectrum that is expected to be assigned for wireless broadband in the near future. For purposes of evaluating the price effects of future auctions on the eve of an auction, it is reasonable to assume that the relevant supply includes the existing spectrum assignments, the additional spectrum being assigned in the upcoming auction, and any spectrum that is likely to be assigned in the next 18 months.[57] Thus, as long as all three auctions are

[57] Exactly how the future spectrum will be incorporated into current expectations and the equilibrium price is complicated and rests on many specifics of how buyers would form expectations. When planning for meeting spectrum needs, firms must take the timing and certainty of future allocations into account. For sure, having opportunities to bid on spectrum in future auctions is relevant to deciding how much to bid for spectrum now. Nevertheless, the further in the future those auctions are, the less salience they will have

spaced at least 18 months apart, the nationwide average price will decrease by just over 6% for each additional 40 MHz of spectrum introduced.

Just as the wireless broadband spectrum price is higher when introducing smaller blocks of spectrum in Table 3, the spectrum prices for the first two auctions will be higher than the price of releasing all 120 MHz at once. For the first auction the estimated price is $1.28 per MHz-pop. The second auction is likely to garner $1.22 per MHz-pop. The price of the final auction will be $1.17 per MHz-pop. In the end, three auctions would likely raise an additional $1.9 billion. See Table 7. In this example, the total additional net revenue from three auctions is $5.3 billion greater than a single auction of 120 MHz.

Table 7. Total Cost of Clearing and Revenue from Multiple Spectrum Auctions

	Total Cost of Clearing *$ Millions* [1]	Estimated Auction Revenue *$ Millions* [2]	Net Expected Revenues *$ Millions* [3]
Auction 1	3,733	14,617	10,884
Auction 2	3,064	13,942	10,878
Auction 3	4,946	13,332	8,386
Total	11,743	41,892	30,149

Sources and Notes: The Brattle Group Analysis.
[1]: Assumes 7 channels (42 MHz) cleared in both auctions 1 and 2, and 6 channels (36 MHz) cleared in auction 3.
[2]: Assumes 40 MHz auctioned in each auction.
[3]: [2] - [1].

in evaluating the value of spectrum available now. Even if it is anticipated, future spectrum introduced beyond a year or two is not likely to be heavily factored into a firms' evaluation of their current spectrum needs and willingness to pay a certain price. For further discussion, see Coleman Bazelon, "Expected Receipts from Proposed Spectrum Auctions," *The Brattle Group*, July 28, 2011. Available at: http://www.brattle.com/_documents/UploadLibrary/Upload964.pdf

G. ROBUSTNESS CONCLUSIONS

Reviewing the factors that appear most likely to affect our estimates shows that our estimates should not be overly sensitive to small variations in the value of the stations or in the number of stations that must be cleared to free up a given amount of spectrum. Our repacking algorithm results in generating a higher estimate than would a more complete algorithm or one that took into account terrain shielding and other factors that might allow tighter packing. Perhaps the greatest uncertainty in our estimate arises from our assumption that the FCC would choose an auction format that provides bidders with strong incentives to bid amounts equal to the amount at which they are indifferent to continuing operation or being bought out. But, overall, our approach is highly conservative because we estimate payments to all broadcasters who relinquish their current UHF license as if they were shutting down when in all likelihood many of them would continue broadcasting in a different band, on a shared signal, with an altered service area of on a different video distribution platform, thus requiring less compensation than estimated.

VII. CONCLUSIONS

Incentive auctions are one way to reallocate spectrum licenses to ensure that spectrum is used in the most valuable way possible. Implementing a combination of a reverse auction to compensate broadcasters for relinquishing some of their current UHF spectrum licenses, and a forward auction to reallocate this cleared spectrum to wireless broadband network operators has been proposed as a means of alleviating the explosive demand for capacity on wireless networks. The solution we propose for repacking is based on both engineering and economic considerations. Specifically, our goal was to find a low-cost solution that would also satisfy frequency interference constraints. We used clearing targets of 120 MHz, 102 MHz and 84 MHz. Results from both our reverse auction analysis, and our estimates of the proceeds from a forward auction of the cleared wireless spectrum are summarized in Table 8. Net revenues are positive for any size band considered. Furthermore, as Figure 2 below indicates, 120 MHz is the size of auction that is expected to maximize federal receipts. Although raising revenue for the government is one benefit of the voluntary incentive auction analyzed here, the greater benefits will come from the increased ability of wireless carriers to provide more wireless broadband at lower cost—a benefit to consumers that has been estimated to be 10 to 20 times the value of the spectrum to producers.[58]

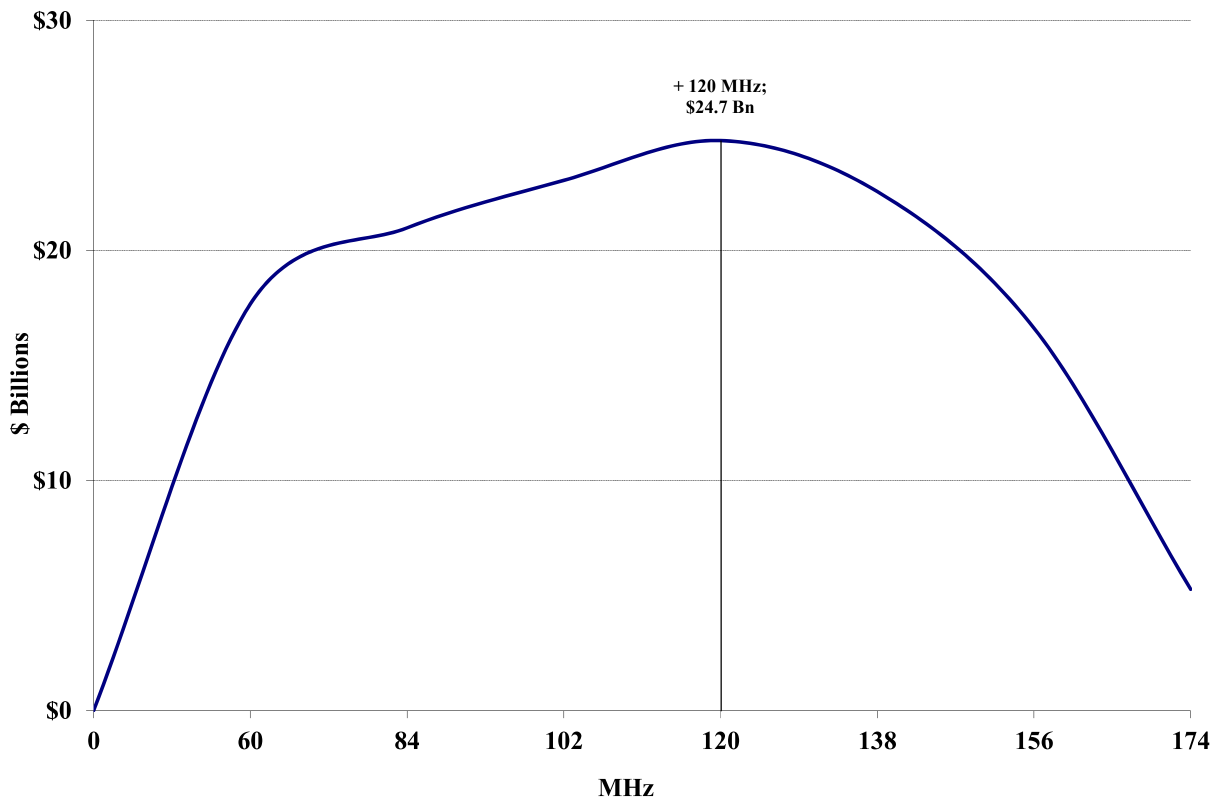
Table 8. Summary of Estimated Spectrum Clearing Costs and Auction Revenues

MHz Cleared	Total Cost of Clearing *$ Millions* [1]	Estimated Auction Revenue *$ Millions* [2]	Net Expected Revenues *$ Millions* [3]
120 MHz	15,220	39,996	24,776
102 MHz	11,634	34,678	23,044
84 MHz	8,166	29,145	20,979

Source: The Brattle Group Analysis.
[1]: Includes cost of both stations returning licenses and stations moving channels.
[2]: For further details see Table 3.
[3]: [2] - [1].

58 For a detailed discussion of this calculation, see Coleman Bazelon, "Response to NDP Consulting Group Concerns Regarding Bazelon 2011," Exhibit C of "Reply Comment of LightSquared Subsidiary," FCC IDP Docket No. 11-109, File No. SAT-MOD-20101118-00239 (August 15, 2011).

Figure 2. Net Auction Revenue Curve



APPENDIX

Table A1. U.S. Separation Requirements

	Separation Distance (km)			
	Co-Channel Zone		Adjacent Channel Zone	
	1	2, 3	1	2, 3
US-UHF - Full Power	196	224	24-110	24-110
US-UHF - Low Power Digital	104	104	20-58	20-51
US-UHF - Low Power Analog	104	104	20-58	20-51

Table A2. Canadian Separation Distance by Station Type

Class	Co-channel (Separation Distance (km))	Adjacent Channel (Separation Distance (km))
A	386	94
B	367	105
C	359	130
VU	371	142
VL	386	149

Table A3. Mexican Separation Distance by Channel Separation

Station Types	Channel Separation	Requirement (Separation Distance (km))
DTV-DTV	Co-channel	0 - 273
DTV-DTV	+/-1	32 - 88
DTV-NTSC	Co-channel	0 - 244
DTV-NTSC	+/-1	10 - 88
DTV-NTSC *	+/-2	24 - 32
DTV-NTSC *	+/-3	24 - 32
DTV-NTSC *	+/-4	24 - 32
DTV-NTSC *	+/-7	24 - 95
DTV-NTSC *	+/-8	24 - 32
DTV-NTSC *	+/-14	24 - 95
DTV-NTSC *	+/-15	24 - 96

* Taboo channels

Table A4. Estimated Cost of Relocating Remaining UHF Stations

			Transmitter Cost [A]	Transmission Line [B]	Transmission Line Installation [C]	Antenna [D]	Antenna Installation [E]	Total [F]
	NTIA Transmission Equipment Cost							
[1]	Full Power	$	950,000	340,000	150,000	375,000	75,000	1,890,000
[2]	Low Power	$	390,000	85,000	90,000	200,000	50,000	815,000
[3]	Minimum Value Reusable	$	350,000	0	0	0	0	
[4]	Probability of Maximum Reuse		50%	50%	50%	50%	50%	
	Expected Cost of Upgrade Equipment and Installation							
[5]	Full Power	$	300,000	170,000	75,000	187,500	37,500	770,000
[6]	Low Power	$	20,000	42,500	45,000	100,000	25,000	232,500
	Allowance for Broadcaster's Administrative Costs							
[7]	Full Power	$						115,500
[8]	Low Power	$						34,875
	Estimated Average Cost of Repacking A UHF Station							
[9]	Full Power	$						885,500
[10]	Low Power	$						267,375

Sources and Notes:
* Full power station based on 60 kW station costs; low power station based on 5 kW station cost.
[1][A] - [2][E]: NTIA Station Equipment Cost estimates downloaded from
http://www.ntia.doc.gov/ptfp/application/EquipCost_tv.html (last visited April 1, 2011.)
[1][F] & [2][F]: [A] + [B] + [C] + [D] + [E], for rows [1] and [2] respectively.
[3] & [4]: TBG Assumption.
[5][A] - [5][E]: (1 - [4]) * ([1] - [3]) for each respective column. [5][F]: [5][A] + [5][B] + [5][C] + [5][D] + [5][E].
[6][A] - [6][E]: (1 - [4]) * ([2] - [3]) for each respective column. [6][F]: [6][A] + [6][B] + [6][C] + [6][D] + [6][E].
[7][F]: 0.15 * [5][F], where administrative costs assumed to be 15% of equipment and installation costs
[8][F]: 0.15 * [6][F], where administrative costs assumed to be 15% of equipment and installation costs.
[9][F]: [5][F] + [7][F]. [10][F]: [6][F] + [8][F].